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ADDRESS OF THE RETIRING PRESIDENT OF THE SOCIETY, IN AWARDING THE BRUCE MEDAL TO ERNEST W. BROWN, PROFESSOR OF MATHEMATICS AT YALE UNIVERSITY.

By Beverly L. Hodghead

The Astronomical Society of the Pacific has now had a successful existence of more than thirty-one years It embraces in its membership most of the astronomers of the Pacific Coast, many in other parts of the world, and many laymen who are keenly interested in the progress of astronomical science. The lay members are of but little service beyond the payment of dues for the upkeep of the Society, but their privileges are many. Aside from the opportunity of pleasant association with the leaders of astronomical thought and discovery which excite a lively interest among many persons who are themselves unacquainted with its more technical and intricate problems, it is to them a school of great value. Climatic conditions in California are favorable to celestial observation. Fortunately, the popular interest aroused by the dissemination of astronomical information has extended to many whose financial substance and generous natures have prompted them to make endowments for the further progress of the Society and advancement of the science. The permanence of the organization is now assured by its large membership, its sound financial condition and its long period of successful existence. Its useful agency is attested by the wide and sustained interest in its proceedings and by the recognized value and high standing of its Publications, which are issued bi-monthly, under the editorial supervision of a publication committee composed of professional astronomers. One of our former presidents, writing recently from Boston, refers in this connection to the estimate of the late Professor E. C. Pickering, who expressed to him the opinion that the Publications of the

Astronomical Society of the Pacific was the best astronomical journal of its kind in existence. This item of self-praise is justified, because a tribute from such eminent authority is deserving of publication, that the Committee may be encouraged by the appreciation which its journal receives. The Committee labors with much professional zeal but without compensation other than the satisfaction of contributing to the advancement of science.

The library of the Society contains in addition to the 31 volumes of its own publications about 6600 books and pamphlets relating to astronomical subjects. Among the most recent additions is the volume which contains the compilation of lectures made possible through the generosity of Mr. Adolfo Stahl, one of the benefactors of the Society. The library is now housed and conveniently indexed and arranged in the Sutro Library in the Stanford University Medical Building, at Webster and Sacramento Streets, San Francisco.

The primary purpose of the meeting tonight is to award the Bruce Medal and to hear the address of Professor Brown, who is to receive it. The meeting is one of the most remarkable in the history of the Society in that it is attended by a larger group of the leading astronomers of the country than has come together here in recent years.

At some risk of repetition, it may be appropriate to explain to the newer members of the Society the history of the Bruce Medal and the manner in which its award from year to year is made. In 1897 Catherine Wolf Bruce endowed the Society with a fund of $2500 to be invested and the interest therefrom used each year for the purchase of a gold medal to be awarded for *distinguished services to astronomy*. The terms of the endowment define the manner in which the award is to be made, which is that the Directors of six of the most prominent observatories in the world—Berlin, Greenwich, Harvard, Lick, Paris and Yerkes, are each invited to nominate three astronomers worthy to receive the medal. From these nominations the award is made by the Directors of the Society. At a meeting of the Directors in March of last year, the observatory of Cordoba, in the Argentine Republic, was substituted for the observatory at Berlin, for reasons which are obvious. The award was suspended during the period of the war, consequently the one given this evening is the fifteenth award to be made.

It is my privilege this evening to announce that the medal for the year just passed, upon the nomination of the six observatories last above referred to and by order of the Directors of the Society, is awarded to Professor Ernest W. Brown of Yale University, and it is no less pleasure to add the announcement that as a result of a very pressing invitation, Professor Brown is with us this evening to receive this medal in person and afford us the pleasure of his acquaintance and to give us an address. It is further in keeping with the custom of my predecessors to follow this announcement with a brief statement of the reasons for the award and a reference to the life of the recipient.

Professor Brown was born at Hull, England, November 29, 1866, and graduated from Christ College, Cambridge, in 1887. He received his master's degree in 1891 and was a fellow in that institution until 1895. From 1891 to and including 1907 he was Professor of Mathematics at Haverford College, Pennsylvania. Since 1907 he has been Professor of Mathematics at Yale University, where the authorities have offered him every facility for the prosecution of his researches and the publication of their results. Professor Brown tells me that his life has been so uneventful that biography is difficult. His story, in brief, is that of a rather delicate youth, carrying on his studies with his father's hearty encouragement and support and emerging, at college, into sturdy manhood with strength for hard study and such vigorous exercise as rowing in the college boats at the races. The record of the years since leaving college is one of quiet study and teaching, with travels in many lands for the necessary recreation.

Astronomy invites specialization, and Professor Brown is a specialist. Like Leuschner, of Berkeley, and Moulton, of Chicago, he has confined his researches almost exclusively to the field of celestial mechanics. Indeed, he has devoted nearly all his spare time for the past thirty years to the single problem of improving our knowledge of the theory of the Moon's motion and of constructing accurate lunar tables. Such work is far less spectacular than the discovery of new planets or other celestial bodies; but that its value is not less to science is attested by the fact that Cambridge University, England, the Paris Academy of Sciences, the Royal Astronomical Society of London, and the Royal Society of London, have anticipated our own action in awarding prizes

and medals to Professor Brown for his distinguished services to astronomy.

It was at the suggestion of his friend and teacher, the late Sir George Darwin, that Brown, while still at Cambridge, began to read G. W. Hill's papers on the lunar theory. This was the beginning of a task happily completed in the present month by the publication of the *Tables of the Motion of the Moon.* The whole ambitious plan was not mapped out at the outset; else its stupendous proportions might well have proved discouraging. His program, rather, developed as the work proceeded. Beginning with an extension of Hill's work, Brown was led gradually to a complete development of a lunar theory that includes "the gravitational action of every particle of matter which can have a sensible effect on the Moon's motion, so that any differences which appear between theory and observation may not be set down to want of accuracy in the completeness with which the theory is carried out. Every known force capable of calculation is included."

When this had been accomplished, by 1908, he undertook the further task of putting the theory completely into numerical form and of constructing tables which would enable the computer conveniently, and in a relatively short time, to calculate the Moon's position for any desired date or series of dates.

I myself must not attempt unassisted to describe or review this great work; it is better to be right than to be an author. Therefore, I have requested and received the assistance of a professional astronomer in arranging the following brief general statement of the problem upon which our medalist has been so long engaged and of the significance of his contribution to its solution. My friend agrees with me that a detailed technical review is unnecessary and would, indeed, be out of place on this occasion.

If the Moon's motion were controlled entirely by the mutual attraction between it and our Earth, and both of these bodies were perfect spheres, its orbit would be a Keplerian ellipse and the solution of the problem of predicting the position of the Moon for any desired epoch would be a simple one. This, however, is not the case; the Sun's attraction, first of all, enters as a powerful disturbing force and the Moon's actual motion thus presents a special case of the famous three-body problem, the complete theoretical solution of which transcends the power of our mathematics. Moreover, the attractions of the planets, each in its

degree, enter either directly or indirectly, and the departure of the Earth's form from perfect sphericity introduces perturbations that are by no means to be neglected. Further, the Moon is relatively so close to the Earth that very minute discrepancies between the observed and predicted motion are at once revealed. Suppose, for example, that the Moon is but a mile or two ahead of or behind its predicted place; such a discordance would be revealed by modern accurate observations. In the case of a satellite of *Jupiter* a difference of *100 miles* between the true and computed places would produce an angular displacement too small to be detected by our most powerful telescopes.

The result of these conditions is that the problem of the lunar motion is by all odds the most complicated one in the whole range of celestial mechanics. A complete solution, as has been said, is beyond our powers—just as, in a very different way, it is beyond our power to find a number whose square shall be precisely two. But just as we can find a number whose square shall differ from two by as small an amount as we please, so, by throwing the mathematical expressions for the Moon's motion into the form of suitable series and taking account of a sufficient number of terms, we may carry our approximate solution to a degree of completeness that will answer the needs of the most accurate modern observations. The development of the necessary expressions, however, presents a problem lying on "the very frontiers of mathematical astronomy, and one that can be dealt with only by the ablest and most skilful analysts." We may properly take pride in the fact that two of our earlier Bruce Medalists—the late Simon Newcomb and the late G. W. Hill—made distinguished contributions to its solution. Our present medalist modestly said, a half dozen years ago, that his own theory was rather the fulfilment to the utmost of the ideas of others than a new mode of finding the Moon's motion. "Its object was severely practical—to find in the most accurate way and by the shortest path the complete effect of the law of gravitation applied to the Moon." Doubtless this statement is correct; unquestionably, Brown is indebted to Hill just as Hill was indebted to Euler. But this does not in the least detract from the merit of his work nor does it imply in him any lack of originality. Indeed, the methods he has employed in his developments exhibit in the most striking way his mathematical resourcefulness and his originality of mind. It is, however, not in my province to enter

upon technical details; let us rather inquire as to the advance in the accuracy of our knowledge of the lunar motions which has resulted from Brown's work.

Here I may to advantage quote the statement of Mr. W. H. Maw, President of the Royal Astronomical Society, in 1907, in awarding the Gold Medal of the Society to Professor Brown. Hansen's *Tables de la Lune*, with one or two corrections supplied by Newcomb, have been used from the date of their publication more than half a century ago up to the present time in most of the national Almanacs; but, says Maw:

> "When Professor Newcomb made his comparison of Hansen and Delaunay, we were in doubt as to the value of some of the coefficients in longitude to the extent of half a second of arc at least; also the motions of the perigee and node were uncertain to correspondingly larger quantities. On the other hand, the degree of accuracy aimed at by our medalist [and, I may interpolate, achieved by him] has been such that there should be included the coefficients of all periodic terms in the longitude, latitude, and parallax which are greater than 0.01 of a second of arc, and that the results should be accurate to this amount."

Now, in one sense, the lunar theory is complete when the analytical expressions showing the action under the law of gravitation of every particle of matter which can have a sensible effect upon the Moon's motion have been worked out. Practically, however, it is also necessary to determine the position, speed and direction of motion of the Moon for some initial date by comparison with actual observations. To secure the required accuracy in the determination of these constants comparison with long series of observations is necessary. At Greenwich the Moon has been observed regularly since 1750, perhaps, on the average, 120 times a year. The resulting 20,000 or more positions, together with shorter series obtained elsewhere, afforded Professor Brown the data he required. It is not implied that he dealt with all these observations from the start. He himself says: "Other workers, notably Airy in the last century and Cowell in this, have done the greater part of the labor. My share was mainly to carry theirs a stage farther by adopting the latest theory and the best modern practice for the reduction of the observations."

Given the theory and these constants expressed in complete numerical form it is only necessary, in order to find the Moon's place at any date, to insert that date and perform the required numerical calculations. But to solve the expressions directly for every desired date would involve a prodigious amount of labor.

Hence the final task was the construction of tables to facilitate the work.

"A table," says Professor Brown, "is mainly a device by which calculations which are continually recurring are performed once for all time, so that those who need to make such calculations can read off the results from the table." The problem was to fit the terms into the smallest possible number of tables and to reduce to a minimum the labor of interpolation between the successive entries in each table. It is, as our medalist says, a problem in combinations, "something like a mixture of a game of chess and a picture puzzle, but unlike the latter in the fact that the intention is to produce ease and simplicity instead of difficulty." Obviously, one man could not, even with the aid of such ingenious devices as the harmonic analyzer invented by Professor Brown, carry out the extensive computations for these tables single-handed. As a matter of fact, our medalist secured the services of Dr. Henry B. Hedrick at the outset, and Dr. Hedrick spent nearly his whole time on the work for nearly nine years, assisted by from one to four computers according to the requirements. Credit is due to Yale University for meeting the cost of these calculations and of the printing and publication of the Tables.

The success achieved may be judged from this statement in the preface to the Tables:

"We have been able by various devices to include every known sensible term and also many that separately must be classed as insensible in comparison with modern observations, but which in the aggregate will occasionally show themselves. Altho nearly 1500 terms are included—nearly five times as many as are contained in Hansen's Tables—the time needed to obtain the annual ephemeris is certainly not greater than, and is probably less than, that which the use of Hansen's Tables demands." It is also stated that final searching tests applied to the proofs revealed only three cases of wrong terms inserted "and these so small as to be only worth mentioning as a matter of record."

It should be added that the ephemeris computed from Brown's Tables will be inserted for the first time in the national Almanacs for 1923.

I may conclude with the statement that our medalist's work supplies a satisfactory solution of the lunar theory under the law of gravitation, but that it does not finally dispose of the problems raised by the Moon's observed motion. As he himself says:

"While many efforts have been made in the past to represent the motion of the Moon by gravitational theory alone, it is now admitted that this cannot

be done completely. When we attempt to represent ancient and modern observations by the same set of constants, it is found that, whatever adjustments be made, there is some disagreement with theory. The same is true of the modern observations. There are oscillating differences which do not correspond to any theoretical gravitational terms, and they are large enough to exclude the possibility of being due to errors either in the theory or in the observations."

No satisfactory explanation for these differences has yet been found.

His *Lunar Theory* and *Tables of the Motion of the Moon* constitute our medalist's most extensive piece of work; but it must not be inferred that his services to astronomy are limited to these researches. In point of fact, he has been engaged upon many problems, including librations in planetary systems, and periodic orbits connected with the Trojan Group of minor planets whose mean daily motions in their orbits about the Sun are almost the same as that of *Jupiter*. Time does not permit me to enter upon any details of these researches.

I now take great pleasure, Professor Brown, in presenting to you, on behalf of the Astronomical Society of the Pacific, and in accord with the award of the Board of Directors, the Bruce Gold Medal. We congratulate ourselves that we are able to add your name to the list of illustrious astronomers who have previously received this award.